OXIDATION OF EXHAUST GASES FROM A BURNING COMPARTMENT IN A REMOTE LOCATION

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Introduction

Compartment fires under fuel rich conditions (typical of post flashover compartment fires) have been shown to produce hazardous levels of carbon monoxide and smoke. External burning occurs when fuel rich exhaust gases spill out of the compartment, mix with air, ignite and burn. Previous research [1] has investigated the effect of external burning on exhaust gases spilling into the open atmosphere mixing with ambient air. That research [1] has shown significant oxidation of carbon monoxide and smoke during sustained external burning of the exhausting gases. However, the leading cause of deaths in compartment fires is carbon monoxide inhalation in neighboring rooms, remote from the fire. The present study focuses on the transport, and oxidation, of fuel rich exhaust gases spilling into enclosed spaces located adjacent to and remotely from a compartment fire.

Experimental Apparatus

The main structure used consists of two levels, a 1.2 x 1.5 x 1.2 m fire compartment located above a 1.2 x 1.4 x 0.3 m high air distribution plenum. The inside of the fire compartment is covered with 2.54 cm thick Fire Master, UL rated, fire insulation board. A 1.8 m long, 30.5 cm diameter air inlet duct allows air to be drawn naturally into the air distribution plenum. The air plenum supplies air uniformly to the fire compartment through two thermally shielded vents, one on each side of the fire compartment floor. Liquid hexane is burned in a circular fuel pan located in the center of the fire compartment floor. The fuel pans used were 15 and 23 cm in diameter, and a depth of 6.4 cm. A window style exhaust vent, centered in the width direction, is located on the front of the fire compartment and opens into a 3.66 m long, 1.14 m wide, and 1.47 m tall hallway. The exhaust vent size is adjustable in order to vary the overall equivalence ratio in the compartment. Exhaust vent sizes used in the hallway experiments varied from 25 x 16 cm to 51 x 24 cm. The hallway ceiling consists of the same fire board as in the compartment and the walls consist of dry wall covered with Fiberfax fireproof insulating sheets.

A 1.5 x 1.5 m hood connected to a 45.7 cm diameter duct collects all exhaust gases exiting the end of the hallway. A gas sampling probe and laser system in the exhaust duct allow for continuous measurement of exhaust species concentrations and soot volume fraction. An orifice plate allows measurement of the volumetric flow rate through the duct. A second gas sampling probe is located inside the hallway together with a thermocouple rake to investigate the evolution of the exhaust gases inside the hallway. The position of both probes is adjustable in three dimensions. The rake holds 9 type K, 30 gage thermocouples spaced 5.1 cm apart in a vertical array. The sampled analysis gas system consists of two Beckman NDIR model 880 analyzers to measure CO and CO_2, a Siemens paramagnetic Oxymat 5E analyzer to measure O_2, and a Gow-Mac FID to measure unburned hydrocarbons as C_2H_4. The fire compartment is also equipped with a stationary vertical rake holding 8 type K, 30 gage thermocouples in the front corner of the compartment. The in-compartment thermocouples are spaced vertically 10 cm apart, starting at 10 cm from the ceiling, and spaced 10 cm from the walls to avoid jet effects. An overall equivalence ratio is obtained by measuring the air flow rate in the inlet duct with a Kurtz velocity probe and the fuel volatilization rate using an A and D 10 Kg load cell.

Results and Discussion

CO, UHC, Soot, and O_2 Levels

Comparison of results from the hallway experiments with those from external jet burning, both measured in the exhaust duct, indicated a significant effect of the hallway on intermediate exhaust species destruction. A comparison of CO yields (Kg CO produced / Kg fuel burned) is given in Figure 1 as a function of the "quasi" steady state equivalence ratio. Note that for equivalence ratios above 1.7, previous research [1] indicates that the CO yield inside the compartment reaches a steady value of about 0.22. Also from previous research on external jet

burning [1], sustained external burning occurred for fires with equivalence ratios above 1.7, resulting in a decrease in CO to 10 - 25 % of in-compartment levels. Results from hallway experiments with sustained external burning indicated less efficient oxidation of CO to 39 - 45 % of in-compartment levels. The lower CO conversion efficiency is attributed to mixing limited combustion of the exhaust gases in the hallway. Similarly to the external jet burning, for all overventilated experiments the CO yield was insignificant.

Shown in Figure 2 are the levels of unburned hydrocarbons inside the compartment and hallway. Although no measurements of unburned hydrocarbons were made in the exhaust duct during external burning in the previous research [1], in-compartment measurements were made and have shown that in-compartment yields reach a steady value of about 0.33 for equivalence ratios above 1.7 [1]. The hallway experiments with sustained external burning indicate fairly efficient oxidation of unburned hydrocarbons to 7 - 17 % of in-compartment levels. This is significantly more efficient oxidation than of CO in the hallway.

A comparison of smoke yields is given in Figure 3, and shows a fair amount of scatter. Results for external jet burning indicated a 50 - 100 % decrease in smoke yield during sustained external burning compared to the levels before external burning occurred [1]. The hallway results show as good as or better smoke oxidation than the external jet experiments, even in the absence of sustained external burning. This may be in part due to soot collection on the hallway ceiling and walls as was observed after experiments. Although soot collects on these surfaces, it has been observed that soot does not continuously accumulate on the hallway surfaces, implying that some soot burnoff is occurring.

The exhaust duct measurements of exhaust gas species show efficient oxidation of unburned hydrocarbons and soot during sustained external burning in the hallway, but inefficient oxidation of carbon monoxide. Hallway sampled experiments were performed to aid in investigating this phenomena. All hallway sampled tests reported in this paper were sampled 5.1 cm from the ceiling, along the centerline of the hallway. The results indicated that CO is oxidized only 5% in the first half of the hallway and another 67% in the second half, as shown in Figure 4. Unburned hydrocarbons on the other hand were oxidized 92% in the first half of the hallway, and another 6% in the second half, as shown in Figure 5. Oxygen concentrations in the hallway were low, as expected, from 0.5% by volume at the compartment end of the hallway to 7.0% at the exhausting end. These results and other research [2,3,4] suggest that the oxidation of carbon monoxide is much slower than the oxidation of unburned hydrocarbons and other species in an oxygen limited environment. Also, temperature measurements in the hallway indicated levels at which CO oxidation becomes very temperature sensitive, around 875 K [1]. Thus, a combination of low oxygen concentrations and temperature sensitivity slow the CO oxidation rate down remarkably in the hallway. The reduced oxidation rate of CO observed here posses a serious threat in compartment fires, as even low levels of CO can be lethal.

Characteristic Equivalence Ratios

Characteristic equivalence ratios, defined as the equivalence ratios where external flashes and sustained external burning begin, were also reported in the previous research for external jet burning [1]. The characteristic equivalence ratios were determined from a video tape of each experiment. Previous results indicated that the characteristic equivalence ratios remained constant with respect to exhaust vent area and fuel pan size [1]. Figure 6 shows these equivalence ratios for the hallway experiments versus exhaust vent area for one fuel pan size (22.9 cm diameter). The data appears to suggest exponential behavior, as would be expected for vent areas approaching zero or infinity. The exhaust vent area (and fuel pan size) acts to limit the ignition source (i.e. flame jets from the compartment) from extending out of the exhaust vent and igniting the exhausting gases. A smaller fuel pan provides a smaller source flame, and a smaller exhaust vent provides a smaller area for the flame to escape. Exponential curves fit to the data are shown in the figure with the regions of external burning indicated.

Summary

The transport of compartment fire exhaust gases through an adjacent hallway has a dramatic effect on the evolution of combustion intermediates. Most notably the oxidation of CO is much reduced; In the hallway CO levels were reduced to 39 - 45 % of those inside the compartment compared to a reduction to 10 - 25 % of in-compartment levels for the external jet burning. Unburned hydrocarbons in contrast are oxidized efficiently, to 7 - 17 % of in-compartment levels, in the hallway experiments. Soot is oxidized as efficient, or more efficient, than in

the external jet experiments, for which a 50 - 100 % reduction of before external burning levels was reported. The inefficient CO oxidation is attributed to a relatively low kinetic oxidation rate as a result of limitations on oxygen availability and temperature levels. Characteristic equivalence ratios, where flashes and external burning begin, display exponential behavior with respect to exhaust vent area. This behavior of characteristic equivalence ratios was not as evident in the external jet experiments. More thorough and detailed hallway experiments will be conducted in the future. The effects of a forced ventilation system in the compartment will also be investigated in the future.

References:

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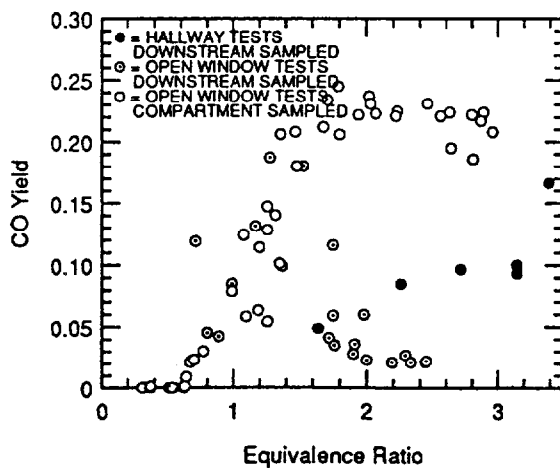
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Figure 1. CO Yield vs. Equivalence Ratio

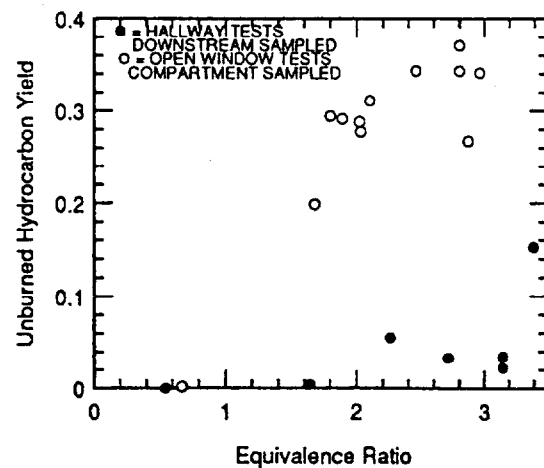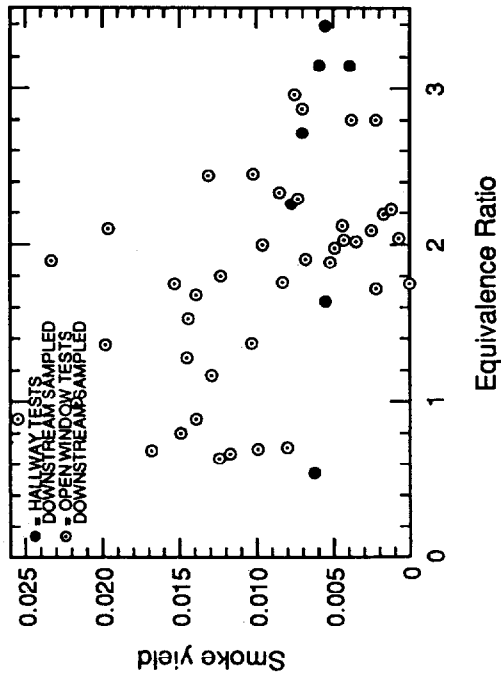
Figure 2. UHC yield vs. equivalence ratio

Figure 3. Smoke yield vs. equivalence ratio

Figure 4 - Wet CO mole fraction versus time for compartment end, middle, and open end of hallway experiments
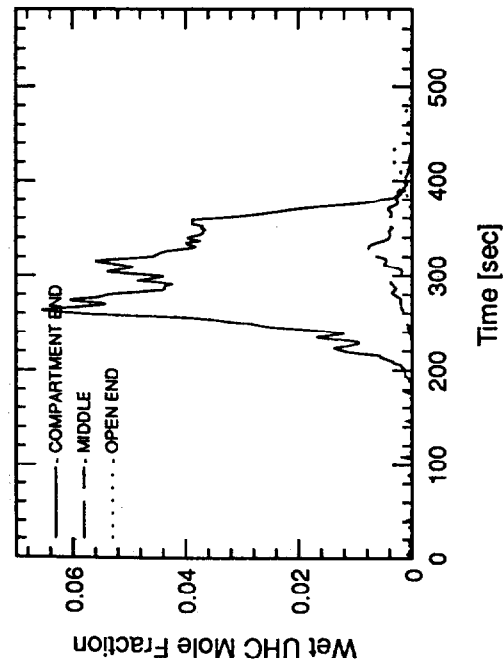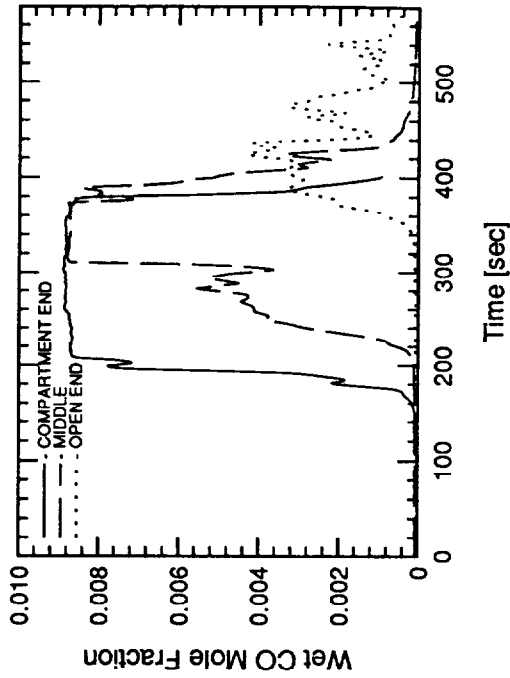

Figure 5 - Unburned hydrocarbon mole fraction versus time for compartment end, middle, and open end of hallway experiments
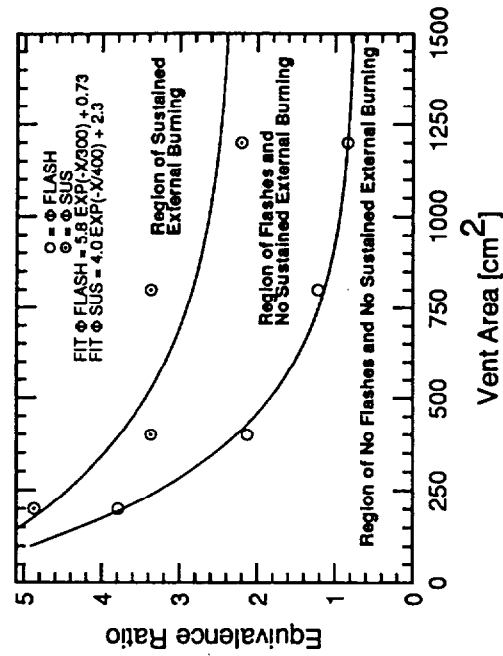

Figure 6. Characterisitic equivalence ratios vs. exhaust vent area for 22.9 cm (9 in) pan hallway experiments, each data point represents the average of several experiments